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Kojima et al.

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(54) **IGNITION COIL HAVING SECONDARY COIL ASSEMBLY AND CONNECTING METHOD FOR THE SAME**

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H01F 27/02 (2006.01)

(52) **U.S. Cl.** **336/90**; 336/96; 336/92

(58) **Field of Classification Search** 336/192, 336/92, 90, 96, 60; 123/634–635
See application file for complete search history.

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(57) **ABSTRACT**

An ignition coil includes a center core, a secondary coil, a primary coil, and an outer core. The secondary coil and the primary coil are substantially coaxially arranged on the outer circumferential side of the center core. The secondary coil includes a secondary winding that is wound around a secondary spool. The secondary spool has a high voltage bracket that includes a secondary terminal. The primary coil includes a primary winding that is wound around a primary spool. The outer core is arranged on the outer circumferential side in the ignition coil. The secondary terminal includes a first connecting portion, which is in a bulb shape, in the tip end. The first connecting portion connects with an end portion of the secondary winding. The first connecting portion is covered with an electrically insulative resin.

27 Claims, 5 Drawing Sheets

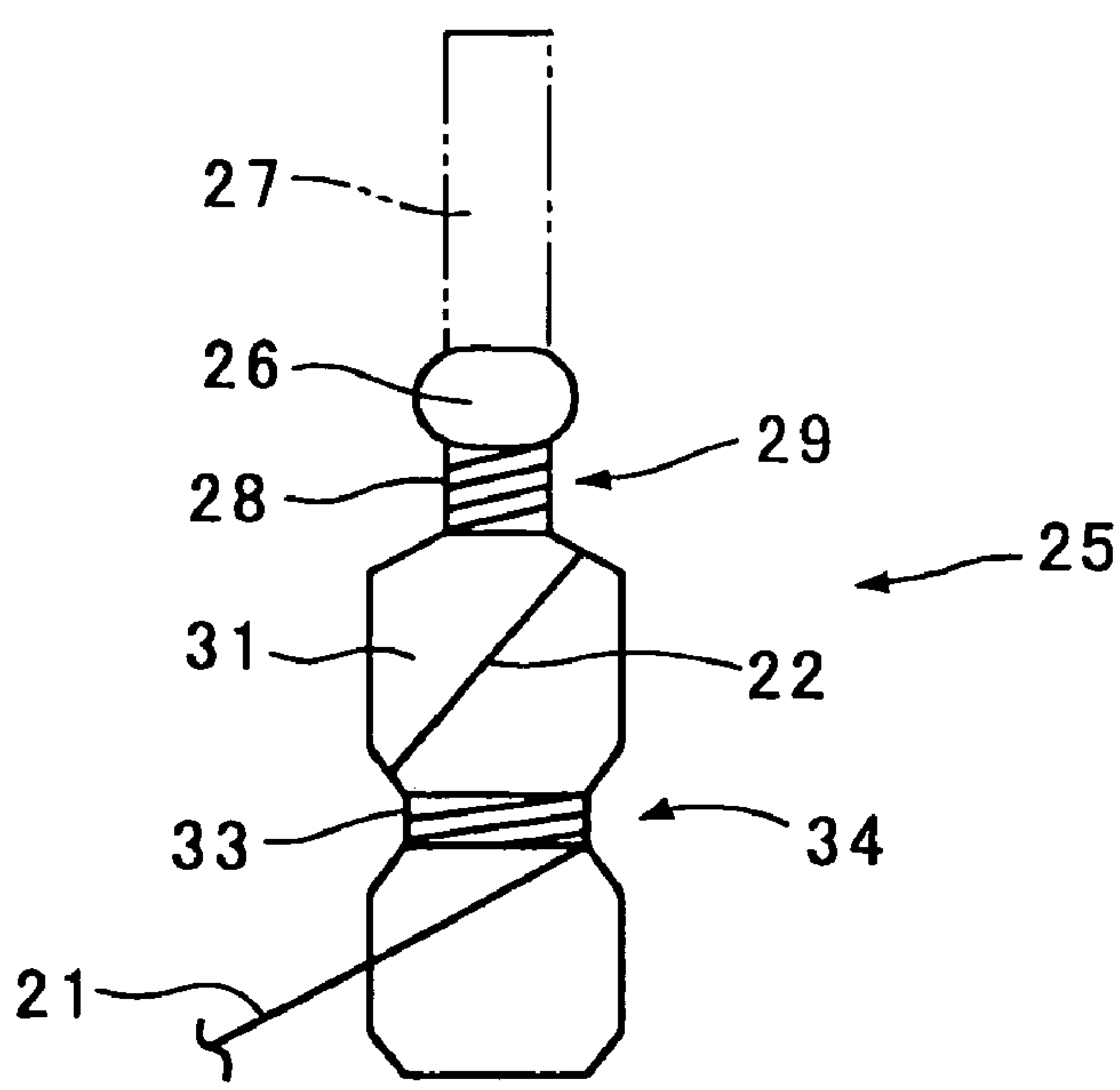


FIG. 1

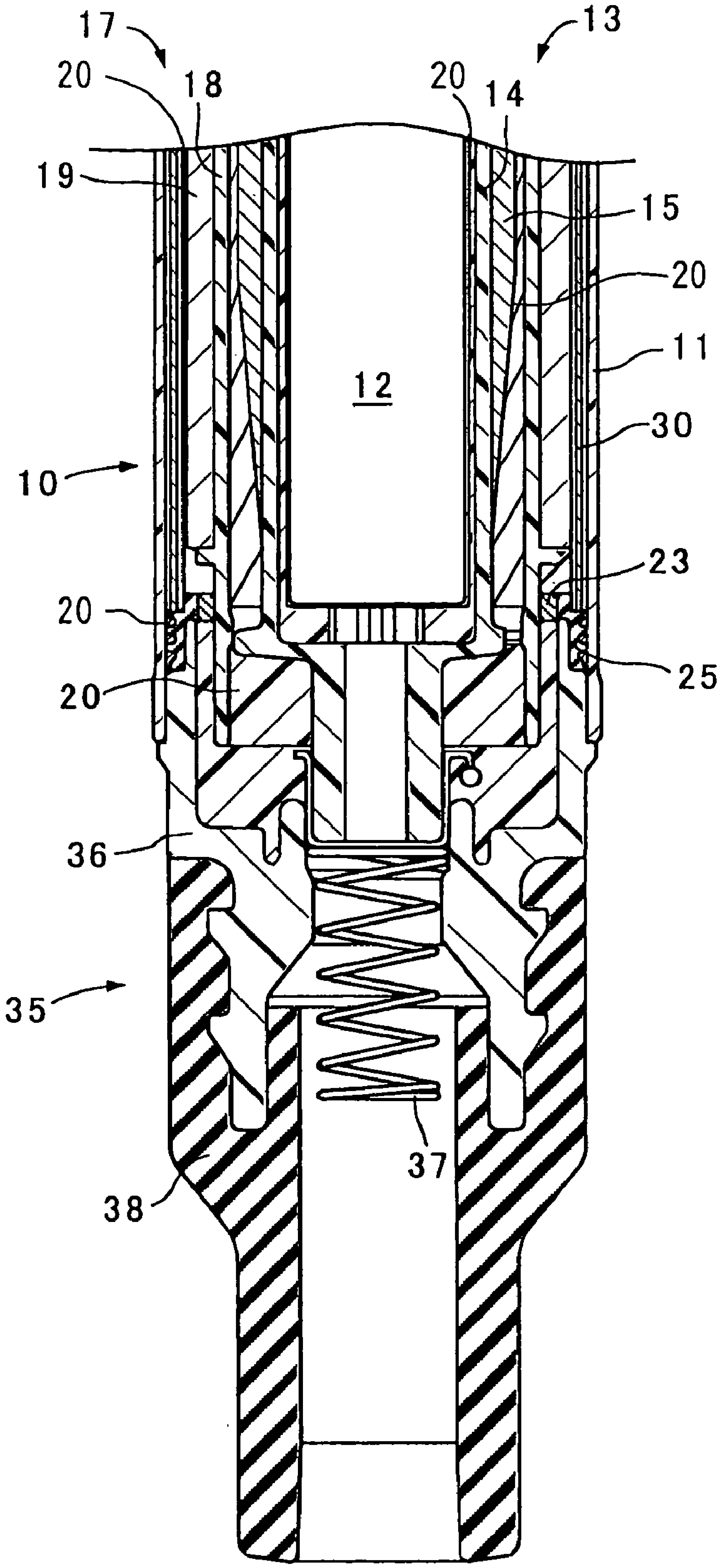


FIG. 2

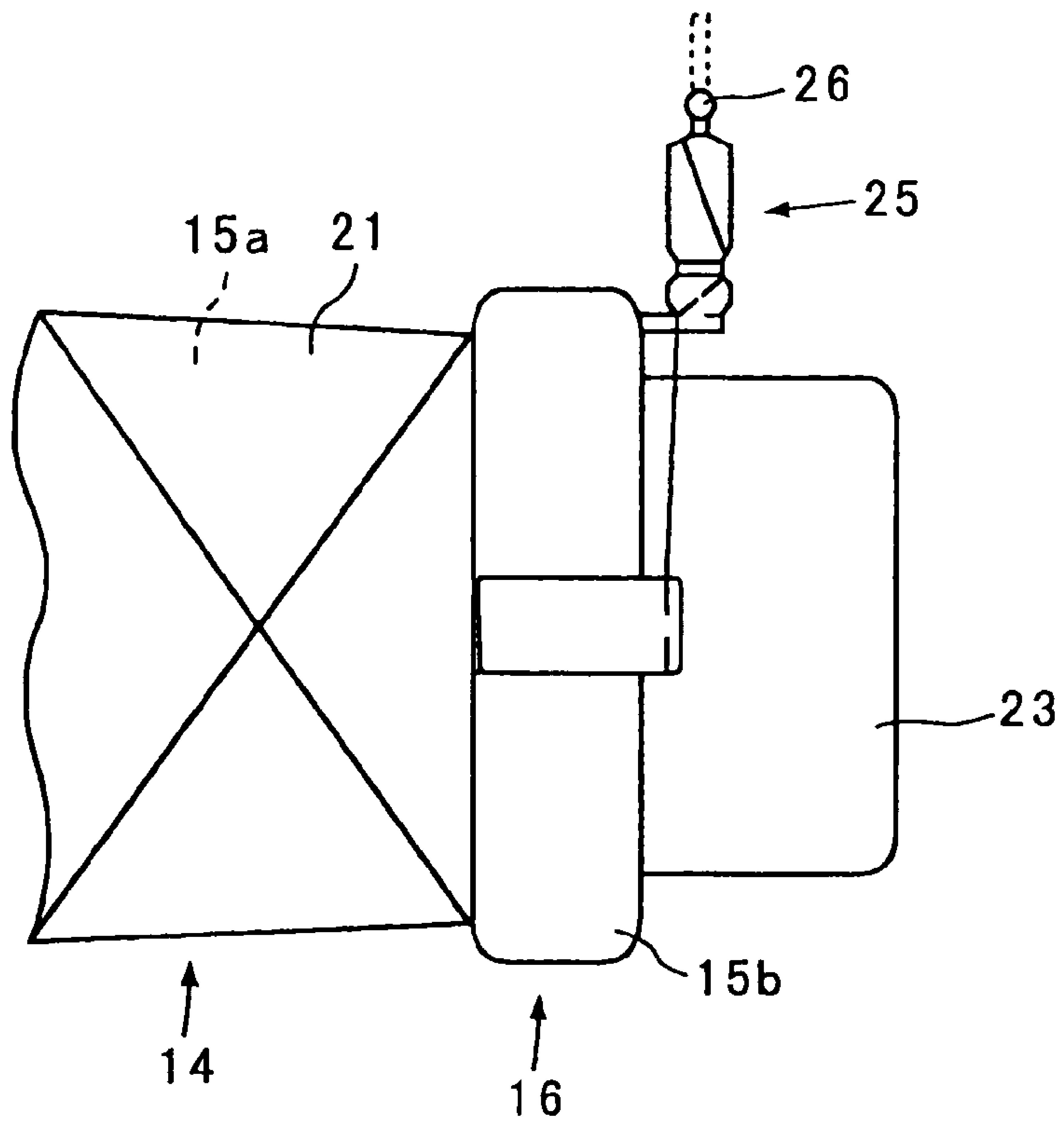


FIG. 3

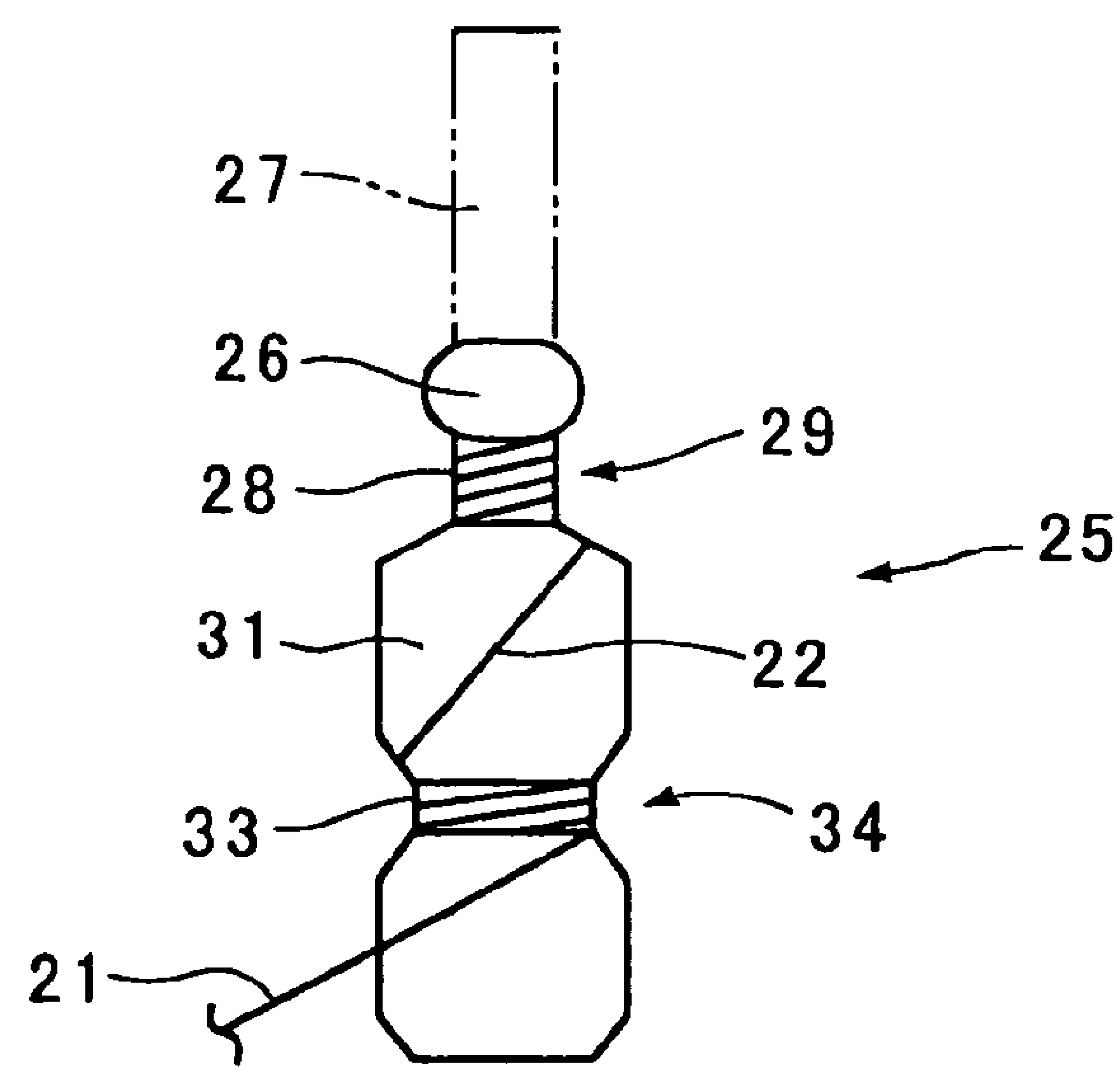


FIG. 4

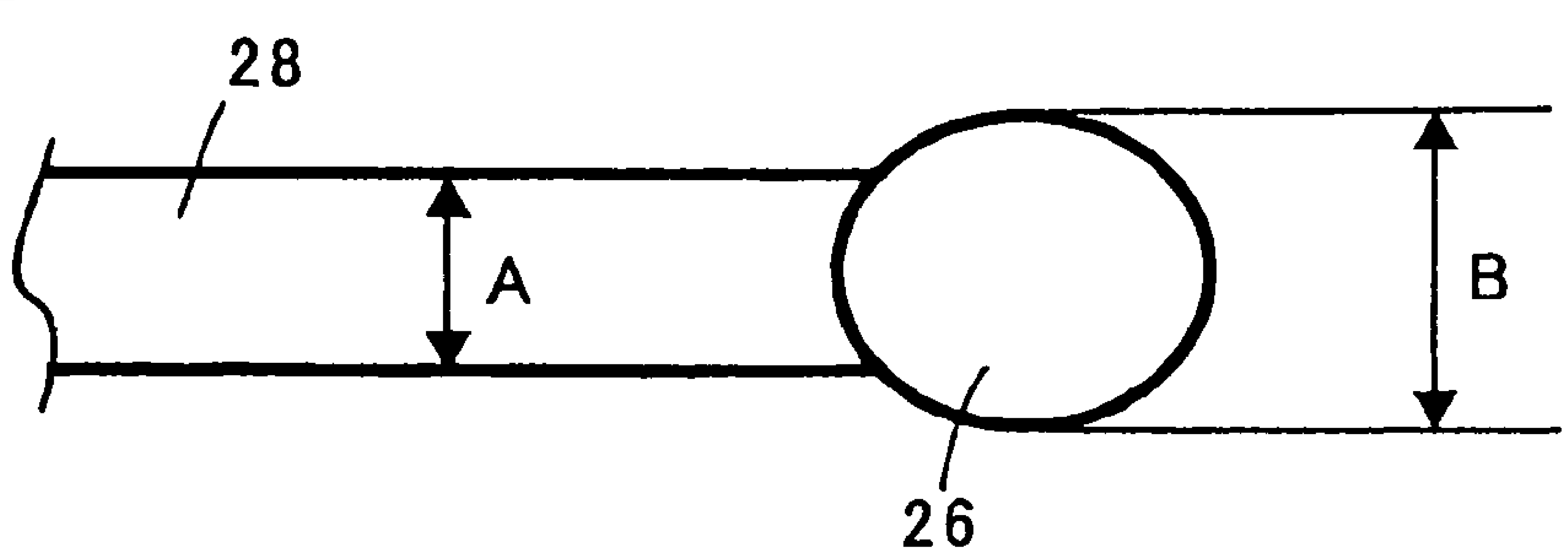


FIG. 5

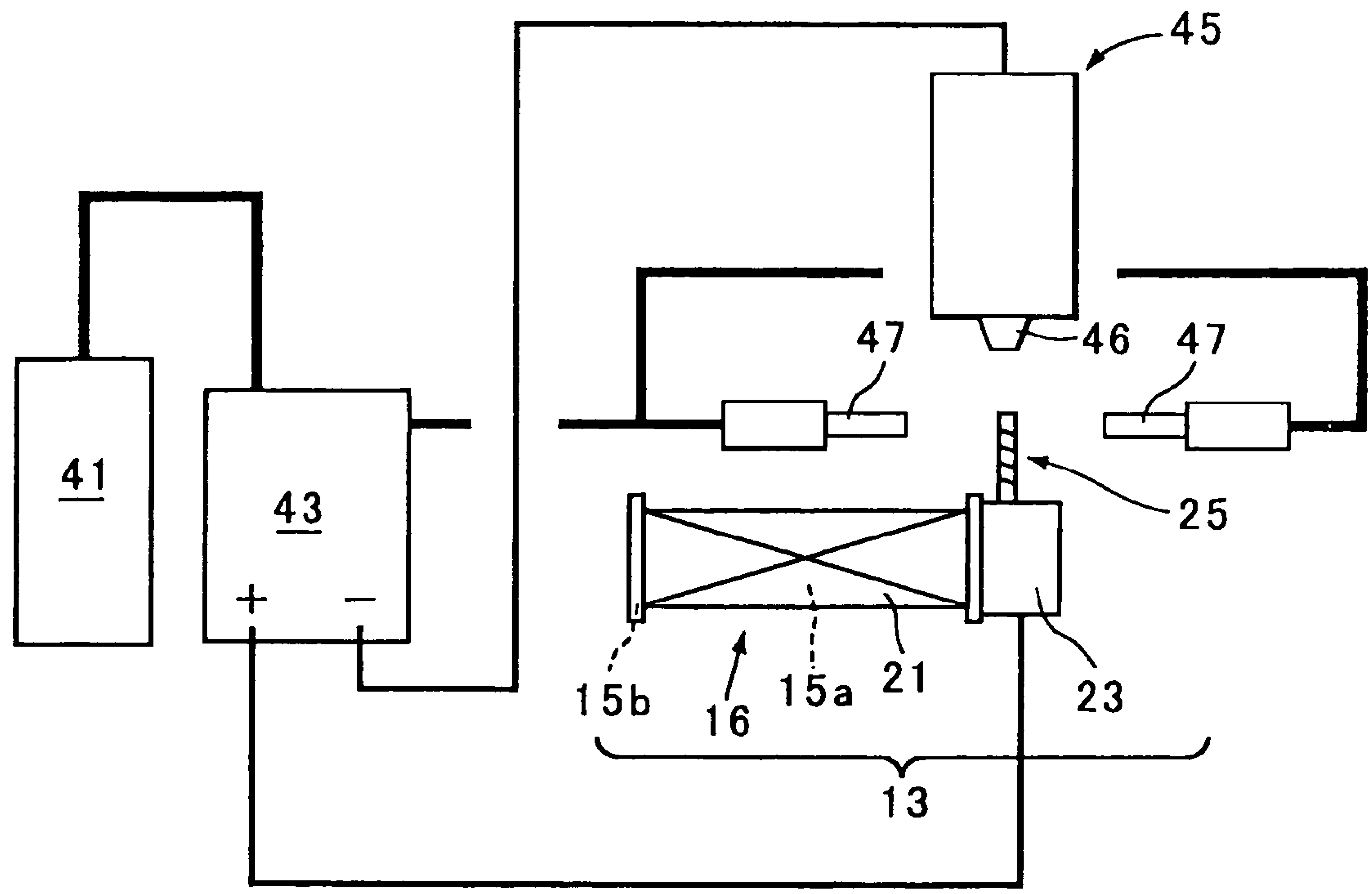


FIG. 6

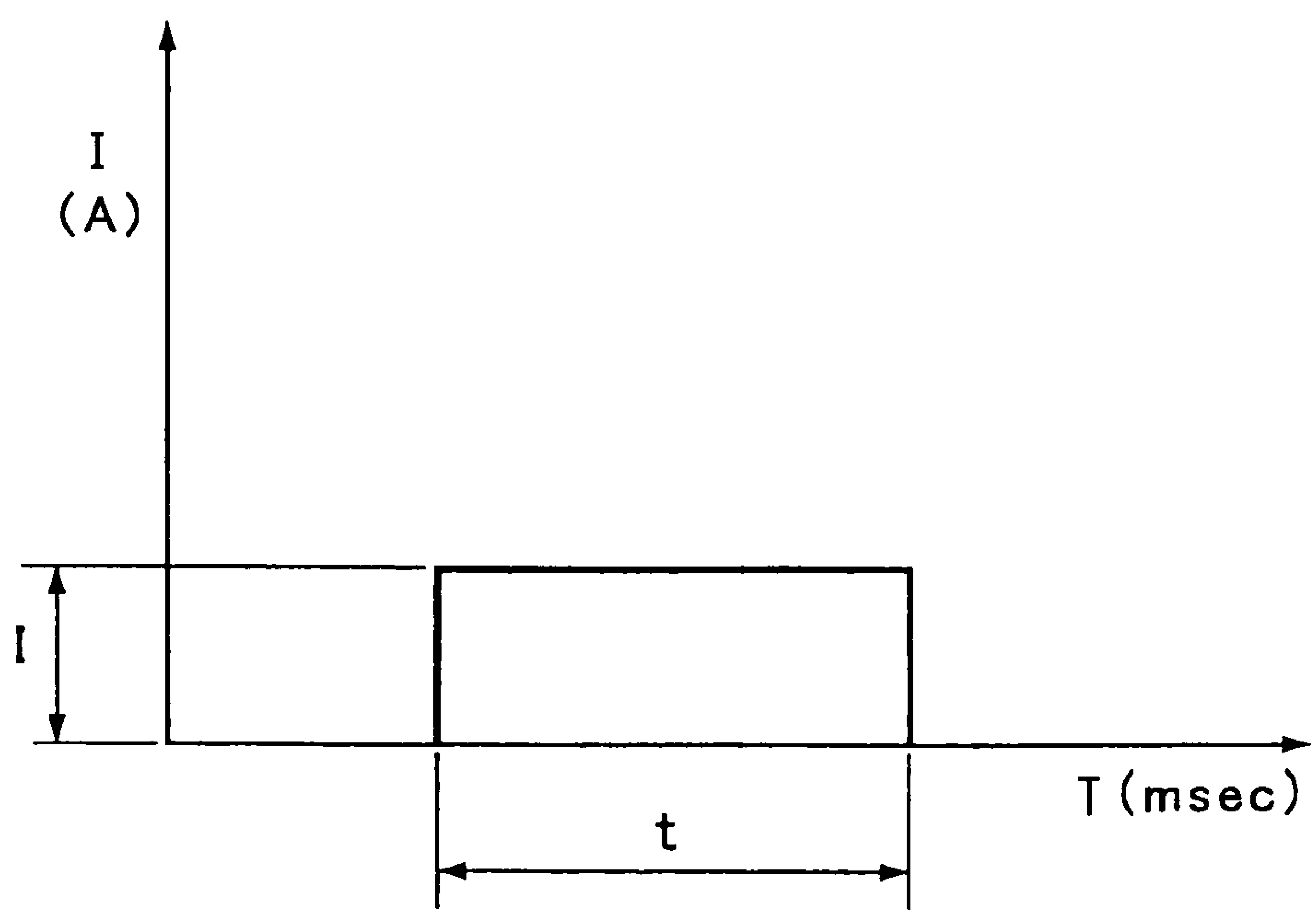


FIG. 7

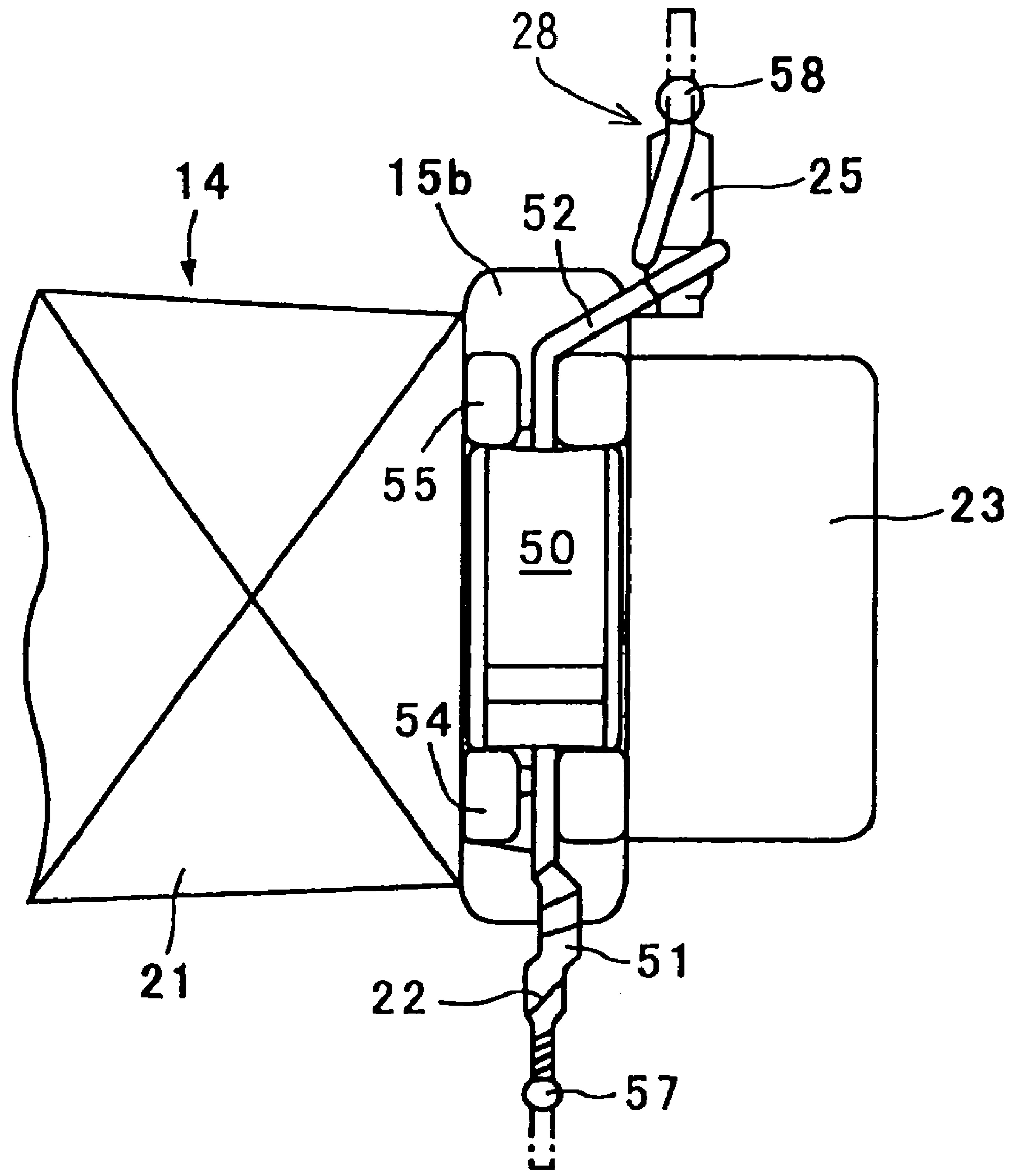


FIG. 9

PRIOR ART

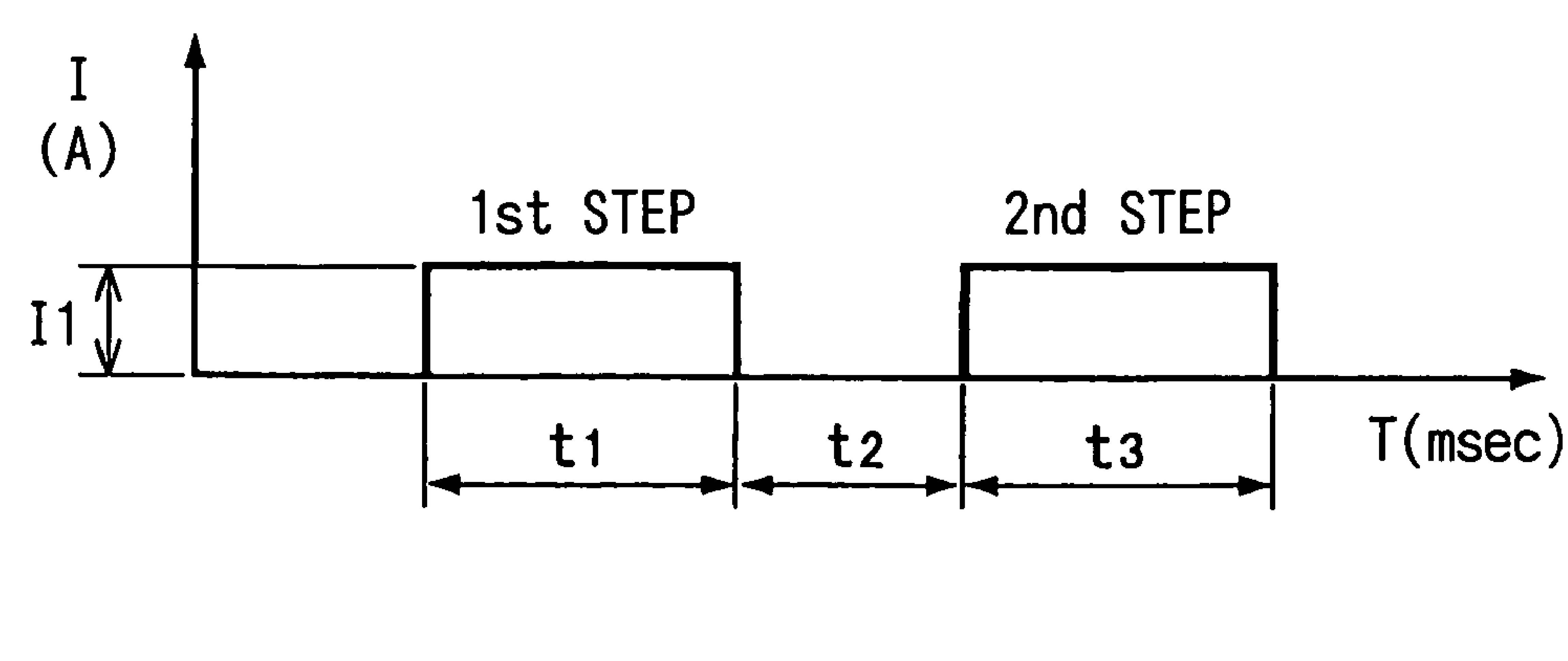


FIG. 8A
PRIOR ART

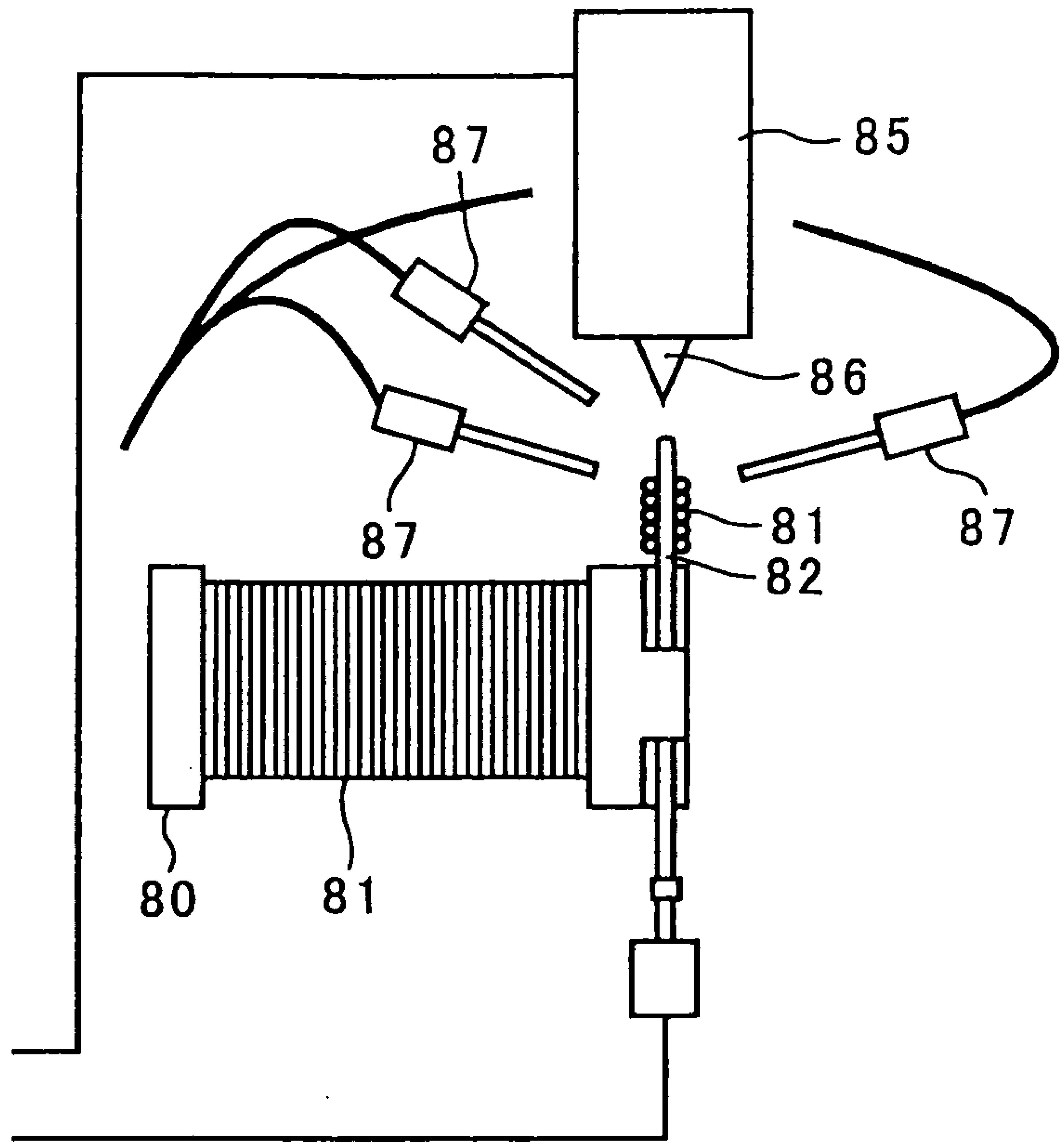
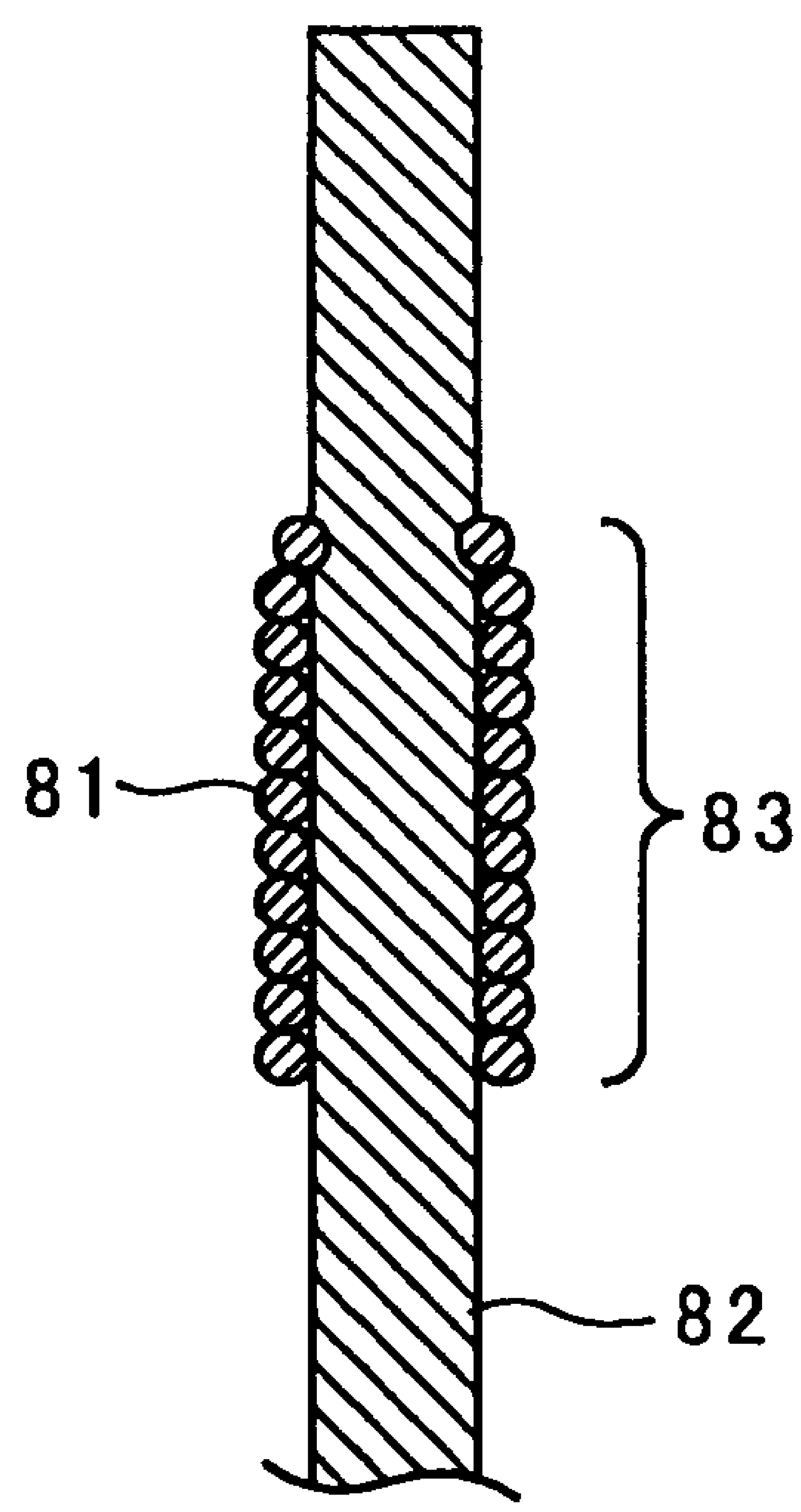


FIG. 8B
PRIOR ART



IGNITION COIL HAVING SECONDARY COIL ASSEMBLY AND CONNECTING METHOD FOR THE SAME

CROSS REFERENCE TO RELATED APPLICATIONS

This application is based on and incorporates herein by reference Japanese Patent Applications No. 2003-427520 filed on Dec. 24, 2003 and No. 2004-324218 filed on Nov. 8, 2004.

FIELD OF THE INVENTION

The present invention relates to an ignition coil that has a second coil assembly, and a connecting method of the second coil assembly.

BACKGROUND OF THE INVENTION

An ignition coil is used for igniting an ignition plug of an internal combustion engine. The ignition coil includes a center core, a primary coil, and a secondary coil. The primary coil includes a primary winding that is wound around a primary spool. The secondary coil includes a secondary winding that is wound around a secondary spool. Current, which is supplied to the primary coil, is shut, so that high voltage is generated in the secondary coil. Both ends of the primary winding and the secondary winding are respectively connected with predetermined terminals by welding. The number of turns of the secondary winding is much greater than the number of turns of the primary winding. The diameter of the secondary winding is much smaller than the diameter of the primary winding. Accordingly, the secondary winding, which is significantly small in diameter, is difficult to be connected with a small-diameter secondary terminal arranged on the high-voltage side.

A conventional connecting method of a coil wire, which is disclosed in JP-A-2003-45735, includes three processes.

As shown in FIGS. **8**A, **8**B, **9**, a coil wire **81**, which has an electrically insulative sheath, is wound around a secondary spool **80**, and a wire end of the coil wire **81** is wound around a coil terminal **82**, to which air is supplied from air nozzles **87** in the first process.

Arc is generated between the coil terminal **82** and an electrode **86** of a torch **85**, so that heat is generated in the coil terminal **82**, and the electrically insulative sheath is flashed from the coil wire **81** of a winding portion **83** in the first heating step of the second process.

Arc is generated between the coil terminal **82** and the electrode **86** of the torch **85**, so that the coil terminal **82** is welded, and the coil terminal **82** is connected with the coil wire **81** of the winding portion **83** in the second heating step of the third process.

The object of the conventional connecting method is to remove the electrically insulative sheath and to connect the coil wire **81** with the coil terminal **82** using a simple method, in which the coil terminal **82** is heated in twice. The electrically insulative sheath is removed from the coil wire **81** in the first heating step, i.e., second process. The coil terminal **82** is welded in the second heating step, i.e., third process after removing the electrically insulative sheath of the coil wire **81**.

When, a secondary wire is wound to a secondary terminal for a significantly large number of turns such as 20000 turns, the secondary terminal becomes thin. In this case, the diameter of the secondary wire becomes significantly small,

such as 50 μm. The conventional connecting method may be applied to the thin secondary terminal, to which the secondary wire of significantly small-diameter is wound for a significantly large number of turns. In this case, degree of electric field increases, and stress concentration arises due to acute shape of the connecting portion, in which the secondary terminal and the secondary wire are welded. Accordingly, an electric tree may be formed and cracking may be caused in an electrically insulative resin located around the connecting portion, as thermal cycles, in which the secondary coil assembly is heated and cooled, is repeated.

In the conventional connecting method, the tip end of the connecting portion is in a bulb-shape, however, increase of electric field and cracking of the electrically insulative resin are not described. Besides, the number of turns of the secondary winding, the diameter of the secondary winding, and the electrically insulative resin around the connecting portion are not described. In the conventional connecting method, the number of turns of the secondary winding may be small, and the diameter of the secondary winding may be large according to the description of the structure. In this structure, the secondary terminal may be thick, and increase of electric field in the tip end of the connecting portion may not be a serious problem. However, voltage generated in the secondary coil may be low, when the number of the winding of the secondary coil is low. Besides, the heating process is divided into two processes in the conventional connecting method. Accordingly, the connecting process takes long, and manufacturing cost may be increased in the conventional connecting process.

SUMMARY OF THE INVENTION

In view of the foregoing problems, it is an object of the present invention to produce an ignition coil including a secondary coil assembly having a secondary winding of significantly small diameter, which is turned for a significantly large number, connected with a tip end of a thin secondary terminal, while generation of electric field in the secondary terminal is restricted, and an electrically insulative resin is protected from forming an electric tree and cracking.

It is another object of the present invention to produce an ignition coil, in which a terminal end of the secondary winding may be easily connected steadily with the tip end of the secondary terminal, even when the diameter of the secondary winding is significantly small, the number of turns of the secondary winding is significantly large, and the secondary terminal has a thin structure.

According to the present invention, an ignition coil includes a center core, a secondary coil, a primary coil, and an outer core. The secondary coil is arranged on the outer circumferential side of the center core. The secondary coil includes a secondary spool and a secondary winding. The secondary spool has a high voltage bracket that is arranged on an end portion of the secondary spool. The high voltage bracket includes a secondary terminal. The secondary winding is wound around the secondary spool. The primary coil is arranged on the outer circumferential side of the center core. The primary coil includes a primary spool and a primary winding. The primary winding is wound around the primary spool. The secondary coil and the primary coil are substantially coaxially arranged. The outer core is arranged on the outer circumferential side of one of the primary coil and the secondary coil that is arranged on the outer circumferential side with respect to the other of the primary coil and the secondary coil. The secondary terminal includes a first connecting portion, which has a bulb shape, in a tip end thereof. The first connecting portion connects with an end portion of the secondary winding of the secondary coil. The first connecting portion is covered with an electrically insulative resin.

A secondary coil assembly includes a secondary coil, in which a secondary winding is wound around a secondary spool, and a high voltage bracket. The high voltage bracket is arranged on an end side of the secondary spool. The high voltage bracket includes a secondary terminal that includes a metallic tip end portion and a first portion. A connecting method of a secondary coil assembly includes a winding process and a welding process.

In the winding process, an end portion of the secondary winding of the secondary coil is wound around the first portion. The first portion is arranged on the side of the secondary spool with respect to the metallic tip end portion, which is in a substantially bar-shape arranged on a side of a tip end of the secondary terminal. In the welding process, the metallic tip end portion of the secondary terminal is welded to form a first connecting portion in a substantially bulb shape, in which the end portion of the secondary winding of the secondary coil assembly is embedded, when the metallic tip end portion is solidified.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention will become more apparent from the following detailed description made with reference to the accompanying drawings. In the drawings:

FIG. **1** is a partially cross-sectional side view showing an ignition coil according to a first embodiment of the present invention;

FIG. **2** is a side view showing a secondary coil assembly according to the first embodiment;

FIG. **3** is an enlarged side view showing the secondary terminal of the secondary coil according to the first embodiment;

FIG. **4** is an enlarged schematic view showing a connecting portion and a tip metallic portion of the secondary terminal according to the first embodiment;

FIG. **5** is an over view showing an arc welding apparatus according to the first embodiment;

FIG. **6** is a graph showing a relationship between current and energizing time according to the first embodiment;

FIG. **7** is a schematic side view showing a secondary coil assembly according to a second embodiment of the present invention;

FIG. **8**A is an over view showing an arc welding apparatus, and FIG. **8**B is a cross-sectional enlarged side view showing a coil wire wound around a coil terminal according to a prior art; and

FIG. **9** is a graph showing a relationship between current and energizing time according to a prior art.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

(First Embodiment)

An ignition coil shown in FIG. **1** includes a coil portion **10**, a high-voltage tower portion **35**, and a control portion (not shown). The coil portion **10** is an axially intermediate portion of the ignition coil. The high-voltage tower portion **35** is located on the lower end side of the coil portion **10**. The control portion is located on the upper end side of the coil portion **10**. The coil portion **10** includes a case **11**, a center core **12**, a secondary coil assembly **13**, a primary coil **17**, and an outer core **30**. The center core **12** is received in the case **11**. The secondary coil assembly **13** is located on the radially outer side of the center core **12**. The primary coil **17** is located on the radially outer side of the secondary coil assembly **13**. The primary coil **17** includes a primary spool **18** and a primary winding **19**. The primary winding **19** is wound around the primary spool **18**.

As shown in FIGS. **1** to **3**, the secondary coil assembly **13** includes a secondary coil **16** and a high voltage bracket **23** (FIG. **2**). The secondary coil **16** includes a secondary spool **14** and a secondary winding **21**. The secondary winding **21** is wound around the outer circumferential periphery of the secondary spool **14**. The high voltage bracket **23** is connected with an end portion of the secondary spool **14**. A secondary terminal **25** extends from the high voltage bracket **23**, and the secondary terminal **25** is bent in the circumferential direction of the secondary spool **14**. The secondary winding **21** has an end portion **22** (FIG. **3**) that is connected with the secondary terminal **25**. An electrically insulative resin **20** is filled into multiple gaps, such as a gap formed between the center core **12** and the secondary spool **14**, a gap around the secondary winding **21** arranged between the secondary spool **14** and the primary spool **18**, a gap around the primary winding **19** arranged between the primary spool **18** and the case **11**, and a portion around the secondary terminal **25**. The outer core **30** is arranged on the outer circumferential side of the primary coil **17**.

As referred in FIG. **1**, the high-voltage tower portion **35** has a cylindrical shape, and includes a tower case **36**, a spring **37**, and a plug cap **38**. The tower case **36** is connected with the lower end of the coil portion **10**. The spring **37** is received in the inner space formed in the tower case **36**, such that the spring **37** resiliently connects with an ignition plug (not shown). The plug cap **38** is made of rubber, and is connected with the lower end of the tower case **36**, such that the plug cap **38** electrically insulate the ignition plug.

As referred in FIGS. **2**, **3**, the secondary spool **14** includes a cylindrical body **15***a* that has a pair of collar portions **15***b* on both axial end sides. The secondary winding **21** is formed of a copper wire that is covered with an electrically insulative sheath. The secondary winding **21** is wound around a concavity formed axially between the collar portions **15***b*. The electrically insulative sheath of the secondary winding **21** is formed of thermostable urethane in consideration of circumstance of use of the ignition coil.

The high voltage bracket **23** is integrally formed with an end portion of the secondary spool **14**. The secondary terminal **25** extends from the high voltage bracket **23** in the substantially radial direction. The end portion **22** of the secondary winding **21** connects with a part of the tip end of the secondary terminal **25**. The secondary terminal **25** is made of phosphor bronze and is covered with an electrically insulative sheath.

The tip end of the secondary terminal **25** has a substantially bulb-shaped connecting portion (first connecting portion) **26**, a small-diameter main turn portion **29**, a large-diameter portion **31**, and a small-diameter dead turn portion **34** in the order from the side of the tip end of the secondary terminal **25**. The end portion **22** of the secondary winding **21** is wound respectively around a first small-diameter portion (first portion) **28** and a second small-diameter portion **33**, so that the main turn portion **29** and the dead turn portion **34** are formed. As shown in FIG. **4**, the outer diameter B of the connecting portion **26** is substantially twice as the width A of the first small-diameter portion **28**. The secondary winding **21** and the secondary terminal **25** are electrically connected with each other in the connecting portion **26** and the main turn portion **29**. A bar-shaped portion (metallic tip end portion) **27**, which is shown by a chain double-dashed line, protrudes from the first small-diameter portion **28**. The bar-shaped portion **27** is welded using arc heating, and the end portion **22** of the secondary winding **21** is covered with the welded bar-shaped portion **27** in a process, in which the bar-shaped portion **27** solidifies. Thus, the substantially bulb-shaped connecting portion **26** and the main turn portion **29** are formed. The bar-shaped portion **27** is formed in a substantially square shape in cross-section, i.e., axial-section. Each side of the square shaped cross-section, i.e., transverse section of the bar-shaped portion **27** is substantially 0.3 mm. The diameter of the bulb-shaped connecting portion **26** is substantially 0.4 mm.

Next, a connecting process, in which the end portion **22** of the secondary winding **21** is connected with the secondary terminal **25** in the secondary coil assembly **13** using an arc welding apparatus, is described in reference to FIGS. **3** to **6**. An arc welding apparatus shown in FIG. **5** is used for TIG welding. The arc welding apparatus includes an inert-gas supply portion **41**, an electric power source **43**, a torch **45**, and a pair of air nozzles **47**. Argon gas is supplied from the inert-gas supply portion **41** into the torch **45** that has an electrode **46** formed of tungsten. The electrode **46** is arranged on the tip end of the torch **45**. The torch **45** and the high voltage bracket **23** are supplied with electric power from the electric power source **43**, so that an arc is generated between the electrode **46** of the torch **45** and the secondary terminal **25** of the secondary coil assembly **13**. The air nozzles **47** supply air for burning the electrically insulative sheath of the secondary winding **21** in the connecting portion **26** (FIG. **3**).

First, the secondary winding **21** is wound around the secondary spool **14** (FIG. **2**), to which the high voltage bracket **23** having the secondary terminal **25** is assembled, for substantially 20000 turns. The diameter of the secondary winding **21** is substantially 0.05 mm. The end portion **22** (FIG. **3**) of the secondary winding **21** is wound around the first small-diameter portion **28** and the second small-diameter portion **33** of the secondary terminal **25**, so that the main turn portion **29** and the dead turn portion **34** are formed. The total protruding length of both the bar-shaped portion **27** and the first small-diameter portion **28** is substantially 2.3 mm. The cross section of the bar-shaped portion **27** is a substantially square that has a dimension such as 0.3 mm×0.3 mm. That is, the bar-shaped portion **27** has the cross section, substantially 0.3 mm square. The above cross section and the protruding length of the bar-shaped portion **27** are determined such that the electrically insulative sheath of the secondary winding **21** is burned, and the secondary terminal **25** is melt by arc heating in the welding portion of the bar-shaped portion **27**.

The electrode **46** of the torch **45** and the secondary terminal **25** of the secondary coil assembly **13** are opposed to each other to form a gap of 0.5 mm to 1.0 mm therebetween. As shown in FIG. **6**, the torch **45** is supplied with a predetermined electricity I (A) for a predetermined period t (msec), while the electrode **46** is shielded, so that an arc is generated between the secondary terminal **25** and the electrode **46**. The predetermined electricity I (A) is preferably 12 (A), and the period t (msec) is preferably 11 (msec).

Simultaneously, inert gas is supplied from the tip end of the torch **45**, and a small amount of air is supplied from the air nozzles **47** to the melting potion of the bar-shaped portion **27** (connecting portion **26**) such that the air does not affect the electrode **46**. The angle and location of the air nozzles **47** are predetermined such that a small amount of air is supplied from the air nozzles **47** to only the connecting portion **26**.

Thermal energy of arc generated between the electrode **46** and the secondary terminal **25** melts the bar-shaped portion **27** (FIG. **3**) and a part of the first small-diameter portion **28** of the secondary terminal **25**, so that the electrically insulative sheath of the secondary winding **21** flashes, i.e., instantaneously sublimes. The end portion **22** of the secondary winding **21** is tucked into the melting material of the bar-shaped portion **27**, so that the bulb-shaped connecting portion **26** is formed in the process, in which the melting material is solidified. Subsequently, the secondary terminal **25** is bent in the circumferential direction of the secondary spool **14** within a predetermined inner diameter such that the secondary coil assembly **13** can be inserted into the cylindrical inner space of the primary coil **17**. The electrically insulative resin **20** is filled in the secondary coil assembly **13**, and the connecting portion **26** is covered with the electrically insulative resin **20**. Thus, the secondary coil assembly **13** is manufactured.

The connecting portion **26**, in which the end portion **22** of the secondary winding **21** is connected with the tip end (metallic tip end portion) of the secondary terminal **25**, is formed in a bulb-shape in the above ignition coil, so that an edge portion can be reduced in the connecting portion **26**. Electric field is apt to increase in the edge portion in a thermal cycle, in which the connecting portion **26** (bar-shaped portion **27**) is heated and cooled, and stress concentration is apt to arise in the edge portion. The edge portion can be reduced in the connecting portion **26**, so that starting point of cracking can be reduced in the electrically insulative resin **20** around the connecting portion **26**, i.e., the electrically insulative resin **20** can be protected from cracking. According to a calculation result of electric field, a degree of electric field is reduced by substantially 25% in the bulb-shaped connecting portion **26** in this embodiment compared with a connecting portion **26** having an edge-shaped tip end.

Besides, the cross section of the bar-shaped portion **27** is substantially square, so that the bulb-shaped connecting portion **26** can be steadily connected with the main turn portion **29**, and the shape of the bulb-shaped connecting portion **26** easily become stable. The total length of the main turn portion **29**, which is melt and solidified, and the connecting portion **26** can be uniformly low within substantially 1.2 mm to 1.4 mm.

When the connecting portion **26** is cooled and solidified, the connecting portion **26** may contract, and the secondary winding **21** may be pulled to the side of the connecting portion **26**. Besides, the secondary winding **21** may be stretched due to thermal stress because of difference between the linear thermal expansion coefficient of the copper wire and that of the electrically insulative sheath of the secondary winding **21**. In this situation, the secondary winding **21** may be disconnected from the connecting portion **26**. On the contrary in the above structure, the dead turn portion **34** is formed on the root side, i.e., side of the secondary spool **14** with respect to the main turn portion **29** in the secondary terminal **25**, so that the length of the secondary winding **21** has a margin, i.e., flexibility. Therefore, the secondary terminal **25** can be protected from disconnecting.

In the above connecting method, the end portion **22** of the secondary winding **21** can be easily and steadily connected with the tip end of the secondary terminal **25**, even the secondary winding **21** has a significantly small diameter such as 0.05 mm, and the secondary terminal **25** has a small cross section, 0.3 mm square.

The reason is, first, the cross-section of the tip end of the bar-shaped secondary terminal **25** is a substantially square, and each side of the substantially square shaped cross-section of the tip end of the bar-shaped secondary terminal **25** is substantially 0.3 mm.

Second, the material of the secondary winding **21** is copper that is sheathed with electrically insulative urethane. The material of the secondary terminal **25** is phosphor bronze. In this combination of the materials, difference of temperature between when the secondary terminal **25** is melt and when the secondary terminal **25** is solidified becomes substantially 180° C., so that the connecting portion **26** is apt to be a substantially bulb shape, i.e., a substantially spherical shape.

Third, the electrically insulative sheath of the secondary winding **21** is flashed substantially simultaneously with melting of the bar-shaped portion **27** of the secondary terminal **25**, so that connecting process can be completed within one-step. As referred in FIG. **6**, the torch **45** may be supplied with the predetermined electricity I (A) for the predetermined period t (msec). Thus, an additional process and an additional treatment for removing the electrically insulative sheath of the secondary winding **21** can be reduced.

In this structure, the number of the turns of the secondary winding **21** of the secondary coil **16** is significantly large, the diameter of the secondary winding **21** is significantly small, and the tip end of the bar-shaped portion **27** of the secondary terminal **25** is thin. Specifically, the number of the turns of the secondary winding **21** is in a range from substantially 10000 to substantially 30000. The diameter of the secondary winding **21** is in a range from substantially 40 μm to substantially 60 μm. The substantially bulb-shaped connecting portion **26**, in which the end portion **22** of the secondary winding **21** of the secondary coil **16** is at least partially welded, is substantially 0.4 mm in radius. Even in this structure, the secondary winding **21** can be stably connected with the connecting portion **26** without disconnecting in the ignition coil.

The diameter of the connecting portion **26** is preferably greater than the width of the tip end of the bar-shaped portion **27** and the thickness of the tip end of the bar-shaped portion **27**. That is, the diameter of the connecting portion **26** is preferably greater than the width of the first small-diameter portion **28** and the thickness of the first small-diameter portion **28**. Specifically, the diameter of the connecting portion **26** is preferably greater than the width of the cross section of the first small-diameter portion **28** and the thickness of the cross section of the first small-diameter portion **28**.

The diameter of the connecting portion **26** set to be large, so that the connecting portion **26** becomes in a bulb shape that is greater than the thickness and the width of the tip end of the bar-shaped portion **27**, i.e., first small-diameter portion **28**. Thus, increase of electric field and stress concentration can be restricted in the connecting portion **26**, i.e., the tip end of the bar-shaped portion **27**. Furthermore, the outer diameter of the connecting portion **26** is preferably 1.2 to 2.5 times of the width of the tip end of the bar-shaped portion **27** and the thickness of the tip end of the bar-shaped portion **27**.

The connecting method of the secondary coil assembly **13** includes a winding process and a welding process. The connecting method of the secondary coil assembly **13** is significantly effective when the connecting method is applied to the high-voltage side, i.e., the side of the ignition plug in the secondary coil assembly **13**. The connecting method of the secondary coil assembly **13** can be applied to the low-voltage side, i.e., the opposite side as the ignition plug in the secondary coil assembly **13**.

The end portion **22** of the secondary winding **21** of the secondary coil **16** is wound around the tip end of the bar-shaped portion **27** of the secondary terminal **25** in the winding process. The tip end of the bar-shaped portion **27** is formed of metal.

The bar-shaped portion **27** has at least the tip end, which is to be welded, and the first small-diameter portion **28**, to which the end portion **22** of the secondary winding **21** is wound, before the tip end of the bar-shaped portion **27** is welded and connected with the secondary winding **21**. The total length of the tip end and the first small-diameter portion **28** of the bar-shaped portion **27** can be within substantially 2.0 mm to 2.6 mm. Furthermore, the second small-diameter portion **33** may be provided to the root side, i.e., side of the secondary spool **14** with respect to the first small-diameter portion **28** in the secondary terminal **25**. A portion of the secondary winding **21**, which extends from the end portion **22** of the secondary winding **21** to the side of the secondary spool **14**, is wound around the second small-diameter portion **33** to be the dead turn portion **34**.

The tip end of the secondary terminal **25** is welded, so that the connecting portion **26** is formed. Alternatively, a part of the tip end and the first small-diameter portion **28** of the secondary terminal **25** are welded with each other, so that the connecting portion **26** is formed. The cross-section of the tip end of the secondary terminal **25** and the like is determined such that an acute portion is not formed in the connecting portion **26** after welding. The cross-section of the tip end of the secondary terminal **25** may be a substantially rectangular shape such as a substantially square and an orthogonal shape, a substantially regular polygonal shape, and a substantially circular shape. When the cross-section of the tip end of the secondary terminal **25** is a substantially rectangular shape, the aspect ratio between the length and the width of the cross section may be in a range from substantially 1:1 to substantially 1:5. The aspect ratio between the length and the width of the cross section is preferably in a range from substantially 1:1 to substantially 1: 2. In this structure, the tip end of the bar-shaped portion **27** and the secondary winding **21** can be stably connected with each other in the secondary terminal **25**. When the cross-section of the tip end of the secondary terminal **25** is a substantially square, each side of the substantially square may be within substantially 0.3 mm to 0.5 mm.

The material of the secondary winding **21** and the secondary terminal **25** of the secondary coil **16** is determined such that an acute portion is not formed in the connecting portion **26** after welding. A typical material of the secondary winding **21** is copper, and a typical material of the electrically insulative sheath of the secondary winding **21** is urethane. The material of the electrically insulative sheath of the secondary winding **21** may be polyester or ester imide. The material of the secondary terminal **25** is copper (pure copper) or a copper alloy, specifically, phosphor bronze (Cu, Sn, or phosphorous), bronze (Cu, Al, Ni, or Mn), or cupronickel (Cu or Ni). The material of the secondary terminal **25** may be an alloy of copper and zinc, pure copper, oxygen free copper, a bronze-type material, or a cupronickel-type material. The secondary terminal **25** is preferably covered with an electrically insulative sheath. Alternatively, a terminal body formed of copper and zinc may be coated with tin, for example.

The tip end of the secondary terminal **25** is welded using arc welding or the like, so that the connecting portion **26** is formed in the welding process. Alternatively, a part of the tip end and the first small-diameter portion **28** of the secondary terminal **25** are welded using arc welding or the like with each other, so that the connecting portion **26** is formed in the welding process. The end portion **22** of the secondary winding **21** of the secondary coil **16** is embedded in the substantially bulb-shaped connecting portion **26** in the process, in which the welded portion is solidified, in the welding process. The arc welding apparatus includes the inert-gas supply portion **41**, the torch **45**, and the air nozzles **47** and the like.

TIG (tungsten inert gas) welding, in which an arc is generated between the electrode **46** and the secondary terminal **25** in an atmosphere of inert gas such as argon-gas, can be used as a typical arc welding.

The metallic tip end of the secondary terminal **25** is welded, such that the metallic tip end does not form any acute portion. Typical shape of the metallic tip end is a substantially bulb-shape, i.e., a substantially spherical shape or a substantially globe shape. However, the shape of the metallic tip end is not limited to the substantially bulb-shape, and the shape of the metallic tip end may be a shape that is similar to a substantially bulb-shape such as a round shape or a substantially oval shape. The length of the connecting portion **26** that is formed on the tip end of the secondary terminal **25** may be within substantially 1.2 mm to 1.4 mm.

(Variation)

At least a portion of the initial turns in the end portion **22** of the secondary winding **21** is preferably incompletely melt in the connecting portion **26**, instead of the above structure, in which all the turns of the end portion **22** of the secondary winding **21** is completely melt in the connecting portion **26**. Specifically, the end portion **22** of the secondary winding **21** has a tip end that is embedded in the connecting portion **26**, and the tip end of the end portion **22** is at least partially intermediately welded in the connecting portion **26**. Alternatively, the tip end of the end portion **22** is at least partially unwelded in the connecting portion **26**. Specifically, the predetermined electricity I (A) and the period t (msec) are controlled in the welding process, so that the welding condition of the secondary winding **21** in the connecting portion **26** can be controlled.

When a portion of the initial turns, i.e., embedded portion in the end portion **22** of the secondary winding **21** is not completely melt in the connecting portion **26**, the portion of the initial turns of the secondary winding **21** has a different structure from the other portion of the connecting portion **26**. In this structure, a boundary face is formed between a portion of the secondary winding **21**, in which the secondary winding **21** is incompletely melted, and the connecting portion **26**, so that tense of the secondary winding **21** can be loosened in the connecting portion **26**, and the secondary winding **21** may be protected from disconnection. As a result, the secondary winding **21** is not apt to be torn even high tension is applied to the end portion **22** of the secondary winding **21**.

The main component of the end portion **22** of the secondary winding **21** is copper, and the copper is not diffused, i.e. not deposited in the surface of the connecting portion **26** in the above structure. Alternatively, the secondary winding **21** and the connecting portion **26** may be welded such that copper, i.e., copper content of the secondary winding **21** is deposited by substantially 50% to 70% in the surface of the connecting portion **26**. The main component (content), i.e., copper of the secondary winding **21** is preferably deposited in the surface of the connecting portion **26**, so that the tip end of the bar-shaped portion **27** and the secondary winding **21** can be stably connected with each other in the secondary terminal **25**. Besides, the color of the main component, i.e., copper is different from the color of the connecting portion **26**, so that existence, i.e., welding of copper can be visually confirmed.

Specifically, the predetermined electricity I (A) and the period t (msec) are controlled in the welding process, so that the welding condition of the secondary winding **21** in the connecting portion **26** can be controlled.

Insulative sheath of the secondary winding **21** is burned, and combustion gas is generated in the welding process. The number of turns of the winding in the bulb-shaped connecting portion **26**, i.e., the number of turns of the secondary winding **21** wound around the bar-shaped portion **27**, which is formed to be the connecting portion **26**, may be large. However, when the number of turns of the winding is large, an amount of combustion gas of the insulative sheath of the secondary winding **21** becomes large in the welding process. The combustion gas may blow welding metal away, and the combustion gas may form a number of blowholes in the bulb-shaped connecting portion **26**. In this case, both the structure and the shape of the bulb-shaped connecting portion **26** may be inappropriate. Therefore, the number of turns of the winding in the connecting portion **26** is preferably equal to or greater than 1, and is preferably equal to or less than 10. The number of turns of the winding in the connecting portion **26** is more preferably equal to or greater than 2, and is more preferably equal to or less than 5.

One of the primary coil **17** and the secondary coil **16** may be arranged on the inner side, and the other of the primary coil **17** and the secondary coil **16** may be arranged on the outer side.

(Second Embodiment)

The ignition coil shown in FIG. **7** has a high-voltage diode **50** in addition to the above structure of the secondary coil assembly **13** in the first embodiment. The high-voltage diode **50** is arranged on the high-voltage side between the end portion **22** of the secondary winding **21** and the secondary terminal **25** for restricting ON-voltage. Specifically, a pair of lead wires **51**, **52** of the high-voltage diode **50** is positioned along two protrusions **54**, **55** that are provided to the collar portion **15***b* of the secondary spool **14**.

The lead wire (first lead wire) **51** of the high-voltage diode **50** is connected with the end portion **22** of the secondary winding **21** via a connecting portion (second connecting portion) **57** using arc welding. The lead wire (second lead wire) **52** of the high-voltage diode **50**, which is arranged on the opposite side as the lead wire **51** with respect to the high-voltage diode **50**, is connected with the secondary terminal **25**, specifically, the tip end (bar-shaped portion **27**) of the secondary terminal **25** using arc welding.

The end portion **22** of the secondary winding **21** of the secondary coil **16** is D1 in diameter. The tip end of the secondary terminal **25** is D2 in diameter. Each lead wire **51**, **52** of the high-voltage diode **50** is D3 in diameter. When the diameters D1, D2, D3 are compared, the diameter D1 of the end portion **22** of the secondary winding **21** is the smallest of the diameters D1, D2, D3. The diameter D2 of the tip end of the secondary terminal **25** and the diameter D3 of the lead wires **51**, **52** of the high-voltage diode **50** are equivalent to each other, in general. Therefore, the end portion **22** of the secondary winding **21** can be connected with the lead wire **51** of the high-voltage diode **50** via the connecting portion

57 in a bulb-shape. Besides, the lead wire **52** of the high-voltage diode **50** can be connected with the tip end of the secondary terminal **25** via a bulb-shaped connecting portion (first connecting portion) **58**.

Next, the connecting method of the second embodiment is described. The high voltage bracket **23** having the secondary terminal **25** is assembled to the secondary spool **14**. The secondary winding **21**, which is substantially 0.05 mm in diameter, is wound around the secondary spool **14** for substantially 20000 turns. The lead wires **51**, **52** of the high-voltage diode **50** are attached into the two protrusions **54**, **55** provided to the collar portion **15***b* of the secondary spool **14**. In this situation, a main turn portion and a dead turn portion are formed in the lead wire **51**, such that the secondary winding **21** can be wound around the main turn portion and the dead turn in the same manner as that of the first embodiment. The end portion **22** of the secondary winding **21** is wound around the lead wire **51** of the high-voltage diode **50**, subsequently the connecting portion **57** is formed using arc welding, so that the secondary winding **21** and the lead wire **51** are connected with each other. The lead wire **52** of the high-voltage diode **50** is wound around the secondary terminal **25**, subsequently the connecting portion **58** is formed using arc welding, so that the lead wire **52** and the secondary terminal **25** are connected with each other.

The torch **45** is supplied with a predetermined electricity for a predetermined period, while the electrode **46** is shielded. Simultaneously, inert gas is supplied from the tip end of the torch **45**, and a small amount of air is supplied from the air nozzles **47** to the melting potion of the connecting portions **57**, **58** in arc welding, in the same manner as that of the first embodiment. Subsequently, the lead wires **51**, **52** of the high-voltage diode **50** and the secondary terminal **25** are respectively bent in the circumferential direction of the secondary spool **14** within the predetermined inner diameter, such that the secondary coil assembly **13** can be inserted into the cylindrical inner space of the primary coil **17**. Thus, the secondary coil assembly **13** is manufactured.

The high-voltage diode **50** may be arranged on the low-voltage side of the secondary coil assembly **13**. Even in this structure, the same effect can be produced.

When the primary coil **17** is energized, ON-voltage is induced in the secondary coil **16**. In this situation, preignition is apt to be caused in the engine. However, the high-voltage diode **50** is arranged between the end portion **22** of the secondary winding **21** and the secondary terminal **25**, so that ON-voltage can be restricted or prevented from being induced in the secondary coil **16**, and preignition can be restricted from arising in the engine.

Besides, the lead wire **51** of the high-voltage diode **50** can be easily connected with the end portion **22** of the secondary winding **21** steadily via the connecting portion **57** that has a substantially bulb-shape. Besides, the lead wire **52** of the high-voltage diode **50** can be easily connected with the tip end of the secondary terminal **25** steadily via the connecting portion **58** that has a substantially bulb-shape. The above effect is obtained by using difference of diameters and difference of the materials of all the end portion **22** of the secondary winding **21**, the lead wires **51**, **52** of the high-voltage diode **50**, and the bar-shaped portion **27**, i.e., tip end of the secondary terminal **25**.

Thus, the high-voltage diode **50**, which is inserted between the secondary winding **21** and the secondary terminal **25**, restricts or prevents from inducing ON-voltage in the secondary coil **16** when the energizing of the primary coil **17** is stopped, so that preignition can be restricted from being caused in the engine.

Various modifications and alternations may be diversely made to the above embodiments without departing from the spirit of the present invention.

What is claimed is:

1. An ignition coil comprising:

a center core;

a secondary coil that is arranged on an outer circumferential side of the center core, the secondary coil including:

a secondary spool having a high voltage bracket that is arranged on an end portion of the secondary spool, the high voltage bracket including a secondary terminal; and

a secondary winding that is wound around the secondary spool;

a primary coil that is arranged on an outer circumferential side of the center core, the primary coil including:

a primary spool; and

a primary winding that is wound around the primary spool, wherein the secondary coil and the primary coil are substantially coaxially arranged; and

an outer core that is arranged on an outer circumferential side of one of the primary coil and the secondary coil that is arranged on an outer circumferential side with respect to the other of the primary coil and the secondary coil,

wherein the secondary terminal includes a first connecting portion, which has a bulb shape, in a tip end thereof,

the first connecting portion connects with an end portion of the secondary winding of the secondary coil,

the first connecting portion is covered with an electrically insulative resins,

the secondary terminal further includes a first portion that connects with the first connecting portion, the first portion arranged on a side of the secondary spool with respect to the first connecting portion,

the first connecting portion has a diameter that is greater than a width of a cross section of the first portion, and

the diameter of the first connecting portion is greater than a thickness of the cross section of the first portion.

2. The ignition coil according to claim **1**,

wherein the secondary terminal further includes a second portion that is arranged on a side of the secondary spool with respect to the first portion,

the secondary winding of the secondary coil has a portion, which extends from the end portion of the secondary winding to a side of the secondary spool, and

the portion of the secondary winding, which extends from the end portion to the side of the secondary spool, is wound around the second portion.

3. The ignition coil according to claim **1**,

wherein the diameter of the first connecting portion is substantially twice as the width of the cross section of the first portion, and

the diameter of the first connecting portion is substantially twice as the thickness of the cross section of the first portion.

4. The ignition coil according to claim **3**, wherein the diameter of the first connecting portion is substantially 0.4 mm.

5. The ignition coil according to claim **1**,

wherein the end portion of the secondary winding has a tip end that is embedded in the first connecting portion, and the tip end of the end portion of the secondary winding is at least partially intermediately welded in the first connecting portion.

6. The ignition coil according to claim **1**,

wherein the end portion of the secondary winding has a tip end that is embedded in the first connecting portion, and

the tip end of the end portion of the secondary winding is at least partially unwelded in the first connecting portion.

7. The ignition coil according to claim **1**,

wherein the secondary winding is wound around the secondary spool for a number of turns that is equal to or greater than 10000 and is equal to or less than 30000, and

the secondary winding has a diameter that is equal to or greater than 40 μm and is equal to or less than 60 μm.

8. The ignition coil according to claim **1**, further comprising:

a diode that includes a first lead wire having a second connecting portion, which has a substantially bulb shape,

wherein the end portion of the secondary winding of the secondary coil is connected with the first connecting portion of the secondary terminal via the diode, and

the end portion of the secondary winding of the secondary coil is connected with the second connecting portion of the first lead wire of the diode.

9. The ignition coil according to claim **8**, wherein the diode includes a second lead wire that is connected with the first connecting portion of the secondary terminal.

10. The ignition coil according to claim **1**, wherein the secondary winding of the secondary coil is formed of a copper wire that is covered with an electrically insulative sheath.

11. The ignition coil according to claim **10**, wherein the copper wire of the secondary winding contains copper content that is deposited by substantially 50% to 70% in a surface of the connecting portion.

12. The ignition coil according to claim **1**, wherein the secondary terminal is formed of one of pure copper and a copper alloy.

13. The ignition coil according to claim **12**,

wherein the secondary terminal is formed of one of phosphor bronze, bronze, cupronickel, an alloy of copper and zinc, pure copper, and oxygen free, and

the electrically insulative sheath of the secondary winding is formed of one of urethane, polyester, and ester imide.

14. The ignition coil according to claim **1**, wherein the first portion of the secondary terminal is substantially rectangular in cross section, which has an aspect ratio in a range from substantially 1:1 to substantially 1:5.

15. A connecting method of a secondary coil assembly, the secondary coil assembly including a secondary coil, in which a secondary winding is wound around a secondary spool, and a high voltage bracket, the high voltage bracket arranged on a side of an end portion of the secondary spool, the high voltage bracket including a secondary terminal that includes a metallic tip end portion and a first portion, the connecting method comprising the steps of:

winding an end portion of the secondary winding of the secondary coil around the first portion that is arranged on a side of the secondary spool with respect to the metallic tip end portion, which is in a substantially bar-shape arranged on a side of a tip end of the secondary terminal in a winding process; and

welding the metallic tip end portion of the secondary terminal to form a first connecting portion in a substantially bulb shape, in which the end portion of the secondary winding of the secondary coil assembly is embedded, when the metallic tip end portion is solidified in a welding process,

wherein the first portion connects with the first connecting portion,

the first portion is arranged on a side of the secondary spool with respect to the first connecting portion,

the first connecting portion has a diameter that is greater than a width of a cross section of the first portion, and

the diameter of the first connecting portion is greater than a thickness of the cross section of the first portion in the welding process.

16. The ignition coil according to claim **15**,

wherein the secondary winding is wound around the secondary spool for a number of turns that is equal to or greater than 10000 and is equal to or less than 30000, and

the secondary winding has a diameter that is equal to or greater than 40 μm and is equal to or less than 60 μm.

17. The connecting method according to claim **15**, wherein the secondary winding of the secondary coil is formed of a copper wire that is covered with an electrically insulative sheath in the winding process.

18. The connecting method according to claim **17**, wherein the copper wire of the secondary winding contains copper content that is deposited by substantially 50% to 70% in a surface of the connecting portion in the welding process.

19. The connecting method according to claim **15**, wherein the secondary terminal is formed of one of pure copper and a copper alloy in the winding process.

20. The connecting method according to claim **19**,

wherein the secondary terminal is formed of one of phosphor bronze, bronze, cupronickel, an alloy of copper and zinc, pure copper, and oxygen free copper, in the winding process, and

the electrically insulative sheath of the secondary winding is formed of one of urethane, polyester, and ester imide, in the winding process.

21. The connecting method according to claim **15**, wherein the metallic tip end portion of the secondary terminal is substantially rectangular in cross section, which has an aspect ratio in a range from substantially 1:1 to substantially 1: 5 in the winding process.

22. The connecting method according to claim **15**,

wherein the secondary terminal further includes a second portion that is arranged on a side of the secondary spool with respect to the first portion,

the secondary winding of the secondary coil has a portion, which extends from the end portion of the secondary winding to a side of the secondary spool, and

the portion of the secondary winding, which extends from the end portion to the side of the secondary spool, is wound around the second portion in the winding process.

23. The connecting method according to claim **15**,

wherein the end portion of the secondary winding has a tip end that is embedded in the first connecting portion, and

the tip end of the end portion of the secondary winding is at least partially intermediately welded in the first connecting portion in the welding process.

24. The connecting method according to claim **15**, wherein the end portion of the secondary winding has a tip end that is embedded in the first connecting portion, and

the tip end of the end portion of the secondary winding is at least partially unwelded in the first connecting portion in the welding process.

25. The connecting method according to claim **15**, wherein the electrically insulative sheath of the secondary winding is at least partially flashed when the metallic tip end portion of the secondary terminal is welded in the welding process.

26. The ignition coil according to claim **15**, wherein the diameter of the first connecting portion is substantially twice as the width of the cross section of the first portion, and

the diameter of the first connecting portion is substantially twice as the thickness of the cross section of the first portion in the welding process.

27. The ignition coil according to claim **26**, wherein the diameter of the first connecting portion is substantially is substantially 0.4 mm in the welding process.

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